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6 UNITED STATES PATENT APPLICATION
7 FOR
8 COMPENSATION OF LATERAL POSITION CHANGES IN PRINTING

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FIELD OF THE INVENTION

The present invention relates to compensation of lateral position changes in printing and, for example, to a method of compensating lateral position changes of a moving recording medium during a print process and to a printing device.

BACKGROUND OF THE INVENTION

Multicolor printers generate images which are composed of a plurality of different single-color images. The quality of the final multicolor image depends on the accuracy of the alignment of the individual images (also called "registration accuracy"). With the increasing resolution of modern printers the registration accuracy has become an issue of interest.

Different printing techniques are known. For example, in ink-jet printing droplets of liquid ink are directed from print heads towards a recording medium. Each print head has a plurality of ink channels. Pulses cause droplets of ink to be expelled as required from dot-forming elements in the form of orifices or nozzles at the end of the channels. These pulses are generated e.g. by thermal components in thermal ink-jet print heads or by piezo-electric elements in drop-on-demand print heads. Page-wide array ink-jet printers have an array of nozzles extending across the full width of the recording medium. The recording medium may be paper or any other suitable substrate to which the ink adheres, and is moved past the print heads by a conveyor formed, for example, by a belt or a drum.

The print heads are arranged in print stations which are typically transversely oriented to the conveyor's advance direction and are spaced apart from each other in the advance direction. Due to the spaced arrangement of the print stations, the individual images are subsequently printed. If the distance between the print stations is smaller than the image length the individual images are printed in a staggered manner. Accordingly, the multicolor image to be printed is virtually separated into individual images to be printed by the respective print stations. In order to achieve registration of the images

1 with respect to the advance direction (or longitudinal direction), the printing
2 activity of the individual print stations is delayed until the image printed by the
3 first print station arrives at the respective subsequent print station.

4 Assuming that the conveyor only moves the recording medium in the
5 longitudinal direction, registration can be achieved by choosing the correct
6 delays. However, small movements in a direction perpendicular to that may
7 cause a lateral displacement of the recording medium from one print station
8 to the other and, accordingly, a lateral misalignment of the individual images.
9 Such lateral displacements may, for example, occur when the conveyor belt
10 runs askew or performs oscillatory lateral movements.

11 In order to also achieve registration with respect to such lateral
12 displacements, it is known to shift the image data to be printed by the
13 individual print stations to compensate for this lateral displacement (see, for
14 example, US patents No. 5,587,771 and 6,335,748).

15 A printing device with a conveyor in the form of a rotating drum is known
16 from US patent No. 6,089,693. The printing device has a single print station.
17 Due to large numbers of dot-forming elements (nozzles) in the print station,
18 generally one or more of the nozzles will be defective. During a first pass (i.e.
19 a first revolution of the drum), the print station prints the complete image, ex-
20 cept for one or more columns corresponding to the defective nozzle or noz-
21 zles. Then the print station is laterally shifted, so that an operative nozzle is
22 aligned to the original position of the defective nozzle. During a second pass
23 (i.e. a second revolution of the drum) the missing column(s) is (are) printed.

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25 SUMMARY OF THE INVENTION

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27 A first aspect of the invention is directed to a printing device. According
28 to the first aspect, the printing device comprises: a plurality of print stations
29 including dot-forming elements arranged to produce an image on a moving
30 recording medium and provided in a redundant manner, thereby enabling dot-
31 forming-element activity to be distributed between redundant dot-forming
32 elements and errors of dot-forming elements to be compensated; a lateral-
33 position detector arrangement or predictor arranged to indicate the recording

1 medium's lateral position relative to the print stations during a print process;
2 and a controller arranged to use at least one print mask for each print station
3 arranged to distribute the dot-forming-element activity and to compensate the
4 errors of dot-forming elements. The printing device is arranged so that, in re-
5 sponse to a detected or predicted change of the relative lateral position, at
6 least one of the currently used print masks is replaced by another one relating
7 to the changed relative lateral position.

8 According to another aspect a printing device is provided, comprising: a
9 plurality of print stations including dot-forming elements arranged to produce
10 an image on a moving recording medium and provided in a redundant man-
11 ner, thereby enabling dot-forming-element activity to be distributed between
12 redundant dot-forming elements and errors of dot-forming elements to be
13 compensated; a lateral-position detector arrangement or predictor arranged to
14 indicate the recording medium's lateral position relative to the print stations
15 during a print process; a controller arranged to use at least one print mask for
16 each print station arranged to distribute the dot-forming-element activity and
17 to compensate the errors of dot-forming elements; and a print-mask memory
18 arranged to store print masks for different lateral recording medium's posi-
19 tions. The controller is arranged, in response to a detected or predicted
20 change of the lateral position, to use at least one other print mask from the
21 stored print masks than the currently used one, this at least one other print
22 mask relating to the changed lateral position.

23 According to another aspect a printing device is provided, comprising: at
24 least one print station including dot-forming elements arranged to produce an
25 image on a moving recording medium; a drum arranged to convey the re-
26 cording medium past the at least one print station, wherein, by performing
27 more than one turn, the drum is enabled to convey the recording medium
28 more than once past the at least one print station, thereby creating an effec-
29 tive dot-forming-element redundancy; a lateral-shift mechanism arranged to
30 perform a relative lateral shift between the print station and the recording me-
31 dium from one drum turn to another drum turn, thereby enabling dot-forming-
32 element activity to be distributed between drum turns and errors of dot-
33 forming elements to be compensated; a lateral-position detector arrangement

1 or predictor arranged to indicate the relative lateral shift between the re-
2 cording medium and the print station; and a controller arranged to use at least
3 one print mask for the at least one print station for each drum turn and each
4 detected or predicted relative lateral position between the print station and the
5 recording medium. The print masks are arranged to distribute the dot-forming-
6 element activity between the drum turns and, in addition, to compensate the
7 errors of dot-forming elements.

8 According to another aspect a printing device is provided, comprising: at
9 least one print station including dot-forming elements arranged to produce an
10 image on a moving recording medium; a drum arranged to convey the re-
11 cording medium past the at least one print station, wherein, by performing
12 more than one turn, the drum is enabled to convey the recording medium
13 more than once past the at least one print station, thereby creating an effec-
14 tive dot-forming-element redundancy; a lateral-shift mechanism arranged to
15 perform a relative lateral shift between the print station and the recording me-
16 dium from one drum turn to another drum turn, thereby enabling dot-forming-
17 element activity to be distributed between drum turns and errors of dot-
18 forming elements to be compensated; a lateral-position detector arrangement
19 or predictor arranged to indicate the recording medium's lateral position rela-
20 tive to the print station; a print-mask memory arranged to store print masks for
21 each drum turn and each detected or predicted relative lateral position be-
22 tween the print station and the recording medium, wherein the print masks
23 are arranged to distribute the dot-forming-element activity between the drum
24 turns and in addition to compensate the errors of dot-forming elements; and a
25 controller arranged to use at least one print mask from the stored print masks
26 for the at least one print station during the printing operation.

27 According to another aspect a method is provided of compensating lat-
28 eral position changes of a moving recording medium during a print process, in
29 which at least one image is printed by a plurality of print stations including
30 dot-forming elements, based on image data. Redundant dot-forming elements
31 are provided, thereby enabling dot-forming-element activity to be distributed
32 between redundant dot-forming elements, and errors of dot-forming elements
33 to be compensated, by using print masks. The method comprises: detecting

1 or predicting the lateral position of the recording medium relative to the print
2 stations during a print process; using the image data and at least one print
3 mask for each print station to distribute the dot-forming-element activity be-
4 tween the print stations and to compensate the errors of dot-forming ele-
5 ments; and replacing, in response to a detected or predicted change of the
6 lateral position, at least one of the currently used print masks by another one
7 relating to the changed relative lateral position.

8 According to another aspect a method is provided of compensating lat-
9 eral position changes of a moving recording medium during a print process, in
10 which at least one image is printed by a plurality of print stations including
11 dot-forming elements, based on image data. Redundant dot-forming elements
12 are provided, thereby enabling dot-forming-element activity to be distributed
13 between redundant dot-forming elements, and errors of dot-forming elements
14 to be compensated, by using print masks, wherein a set of such print masks
15 for different relative lateral positions of the recording medium is pre-calculated
16 and stored. The method comprises: detecting or predicting the lateral position
17 of the recording medium relative to the print stations during a print process;
18 using the image data and at least one print mask for each print station to dis-
19 tribute the dot-forming-element activity between the print stations and to com-
20 pensate the errors of dot-forming elements; and using, in response to a de-
21 tected or predicted change of the relative lateral position, at least one other
22 print mask from the stored print masks than the currently used one, this at
23 least one other print mask relating to the changed relative lateral position.

24 According to another aspect a method is provided of compensating lat-
25 eral relative position changes of a moving recording medium during a print
26 process, in which at least one image is printed, based on image data, by at
27 least one print station of a drum system during more than one drum turn. Ef-
28 fective dot-forming-element redundancy is created by executing additional
29 drum turns and laterally shifting the print station between drum turns, thereby
30 enabling dot-forming-element activity to be distributed between the drum
31 turns and errors of dot-forming elements to be compensated, by using print
32 masks. The method comprises: detecting or predicting the lateral position of
33 the recording medium relative to the at least one print station during a print

1 process; using the image data and at least one print mask for each print sta-
2 tion for each drum turn and detected or predicted relative lateral position be-
3 tween the print station and the recording medium, wherein the print masks
4 distribute dot-forming-element activity between the drum turns and, in addi-
5 tion, compensate the errors of dot-forming elements.

6 According to another aspect a method is provided of compensating lat-
7 eral relative position changes of a moving recording medium during a print
8 process, in which at least one image is printed, based on image data, by at
9 least one print station of a drum system during more than one drum turn. Ef-
10 fective dot-forming-element redundancy is created by executing additional
11 drum turns and laterally shifting the print station between drum turns, thereby
12 enabling dot-forming-element activity to be distributed between the drum
13 turns and errors of dot-forming elements to be compensated, by using print
14 masks. A set of such print masks for different relative lateral positions of the
15 recording medium is pre-calculated and stored. The method comprises: de-
16 tecting or predicting the lateral position of the recording medium relative to the
17 at least one print station during a print process; and using the image data and
18 at least one print mask from the stored print masks for each print station for
19 each drum turn and detected or predicted relative lateral position between the
20 print station and the recording medium, wherein the print masks distribute
21 dot-forming-element activity between the drum turns and, in addition, com-
22 pensate the errors of dot-forming elements.

23 Other features are inherent in the methods and products disclosed or
24 will become apparent to those skilled in the art from the following detailed de-
25 scription of embodiments and its accompanying drawings.

26

27 DESCRIPTION OF THE DRAWINGS

28

29 Embodiments of the invention will now be described, by way of example,
30 and with reference to the accompanying drawings, in which:

31 Fig. 1 illustrates an embodiment of a printing device having a belt
32 conveyor;

33 Fig. 2 illustrates an embodiment of a lateral-position detector ar-

1 arrangement with longitudinally extending encoding marks;

2 Fig. 3 illustrates another embodiment of a lateral-position detector
3 arrangement with angled encoding marks;

4 Fig. 4 illustrates print control of two redundant print stations for six
5 different cases (a-f), including cases with a lateral recording medium shift and
6 different attempts to compensate it (b-f);

7 Fig. 5 is a flow diagram illustrating pre-calculation of print masks
8 and their use during printing in order to compensate lateral position changes;

9 Fig. 6 illustrates another embodiment of a printing device having a
10 drum conveyor.

12 DESCRIPTION OF THE PREFERRED EMBODIMENTS

14 Fig. 1 illustrates an embodiment of a printing device. Before proceeding
15 further with the detailed description of Fig. 1, however, a few items of the em-
16 bodiments will be discussed.

17 In some of the embodiments, the printing device is equipped with a plu-
18 rality of print stations which are successively passed by the recording medium
19 conveyed by a conveyor (e.g., a belt) during a print process. The print stations
20 are arranged to print single-color images. In embodiments enabling multicolor
21 images to be printed, each print station prints a part of the entire multicolor
22 image. The printing is based on input image data virtually separated into data
23 representing the individual image parts printed by the respective print sta-
24 tions. A multicolor image is typically separated into four single-color images
25 (the separation is, for example, based on the basic colors cyan, magenta,
26 yellow and black). As will be explained below, the print stations have dot-
27 forming elements (e.g. nozzles) which, in some of the embodiments, are ar-
28 ranged in a redundant manner for each individual color. In some of these em-
29 bodiments, the redundancy is achieved by doubling the print stations for each
30 color; i.e. these embodiments have two cyan, magenta, yellow and black print
31 stations. In other embodiments, each single-color print station has a redun-
32 dant arrangement of dot-forming elements, e.g. four print stations with two
33 page-wide arrays of dot-forming elements. Redundant print stations (or re-

1 redundant arrangements of dot-forming elements) form what is called a "redundancy group"; for example, two redundant print stations of the same color
2 form a redundancy group.

3
4 In other embodiments, redundancy is not achieved by doubling (or multiplying)
5 the number of print stations of the different colors, but rather by doubling
6 (or multiplying) the number of times the recording medium is moved past
7 a print station (i.e. the number of passes), and by laterally shifting the print
8 station relative to the recording medium between two subsequent passes. In
9 some of these other embodiments, the conveyor is in the form of a rotating
10 drum facing a print station (or several print stations for different colors). The
11 recording medium is attached to the surface of the drum, and the several
12 passes of the recording medium are performed by repeated revolutions of the
13 drum.

14 The redundancy (either achieved by multiplying the number of print stations
15 or the number of passes) enabling the dot-forming-element activity to be
16 distributed between the redundant dot-forming elements or the different
17 passes. For example, the first print head of two redundant print heads prints
18 about one half of the dots or of the picture elements (analogously, during a
19 first pass the first half may be printed, and during a second pass the second
20 half), and the second print head prints the other half. Generally, the print activity
21 may be distributed such that blocks of contiguous dots or picture elements
22 printed by one print station or in one pass are minimized or, at least,
23 reduced, which improves image quality. For example, in the case of a distribution
24 between two print stations or passes, the print activity may be distributed
25 according to a checkerboard-like pattern. Furthermore, the redundancy enables
26 an "error hiding", i.e. defective (or faulty) dot-forming elements to be
27 compensated by operative dot-forming elements, as will be explained in more
28 detail below. In embodiments in which redundancy is achieved by several
29 passes, the print station and the recording medium are laterally shifted relative
30 to each other between passes, in order to enable an operational dot-forming element
31 to take over the function of a faulty one, in the second pass.

32 Distributing the print activity means, herein, distributing it to a greater extent
33 than would be required to obtain only error hiding. In other words, it

1 means that the print activity is distributed between different print stations or
2 passes, even in the case in which all dot-forming elements are operational
3 (i.e. in the case in which no errors are hidden). In contrast, in the US patent
4 No. 6,089,693 mentioned at the outset, not distributed printing is performed
5 since everything is printed during the first pass, but only the task of the defec-
6 tive nozzles is performed by shifted operational nozzles during the second
7 pass (i.e. nothing is printed in the second pass if all nozzles are operational).

8 In the embodiments, the recording medium is paper or any other suit-
9 able substrate. It may be subdivided in sheets (e.g. paper sheets). A print
10 process may extend over one sheet or several sheets.

11 In some of the embodiments, the recording medium is advanced by a belt con-
12 veyor in the longitudinal direction. While conveyed past the print stations, the re-
13 cording medium may change its lateral position. The recording medium's dis-
14 placement in the lateral direction may, for example, be due to a correspond-
15 ing lateral belt displacement occurring during the mainly longitudinal belt
16 movement. In embodiments having a drum conveyor, the recording medium
17 may also move laterally relative to the drum during the drum revolutions. Fur-
18 thermore, shifting the print station between two drum revolutions also repre-
19 sents a relative lateral shift between the recording medium and the print sta-
20 tion. When the mechanism causing the lateral shift of the print station is not
21 controlled to a precision corresponding to the print resolution, an uncontrolled
22 relative lateral movement between print station and recording medium will
23 appear from one drum revolution to the other. In principle, a lateral displace-
24 ment of the drum might also occur.

25 A lateral displacement between the different print stations, or the differ-
26 ent revolutions, would, in principle, result in a "misregistration" of the individ-
27 ual images printed. In order to enable such a lateral displacement to be com-
28 pensated, the recording medium's relative lateral position is either detected or
29 predicted for each print station. In some of the embodiments, the detection or
30 prediction is indirect, in the sense that the belt's or drum's lateral position is
31 detected or predicted for each print station, and it is assumed that a detected
32 or predicted lateral position change of the belt or drum causes a correspond-
33 ing lateral position change of the recording medium. In belt-conveyor em-

1 bodiments with lateral position detection, a lateral-position detector arrange-
2 ment is provided at each print station. For example, in one embodiment, the
3 conveyor belt is equipped with encoding marks indicative of the belt's lateral
4 position (e.g. encoding marks with two angled positions), and the sensor ar-
5 rangement has sensors responsive to the encoding marks and arranged to
6 determine the belt's lateral position from the detected encoding marks.

7 In other embodiments (belt or drum embodiments) the encoding marks
8 may be applied to (e.g. printed on) the recording medium itself, in order to
9 directly detect the recording medium's relative lateral position.

10 In still other embodiments, in which a recording medium with an irregular
11 surface structure (such as a paper-fiber structure) is used, the detector ar-
12 rangement is arranged to directly detect the recording medium's lateral posi-
13 tion without such pre-applied marking on the recording medium. Images of
14 the surface structure are taken with the detector arrangement at the first print
15 station, or during the first drum revolution, as the recording medium ad-
16 vances, and are stored in a memory. At the second (or subsequent) print sta-
17 tion, or drum revolution, images of the surface structure are taken with the
18 detector arrangement and compared with the corresponding stored surface
19 images taken at the first print station, or drum revolution. A lateral shift of the
20 second images shifted with respect to the stored first ones can be detected
21 and used as an indication of a corresponding lateral shift of the recording
22 medium. However, basing the lateral-shift detection on a comparison of dif-
23 ferent surface images implies that a lateral shift can only be detected when
24 the shifted recording medium reaches the second detector, or when the sec-
25 ond revolution is performed. A suitable surface image recording device is de-
26 scribed in US patent No. 6,118,132.

27 In still other drum embodiments the lateral-position detector arrange-
28 ment detects the actual lateral position of the laterally movable print sta-
29 tion(s).

30 In some embodiments, the lateral conveyor or recording medium posi-
31 tion depends, in a reproducible manner, on a known parameter of the con-
32 veyor (which is, for example in a belt embodiment, the case if the belt pro-
33 duces a reproducible lateral oscillation depending on the longitudinal belt po-

1 sition). This enables the lateral conveyor or recording medium position to be
2 predicted for each print station or drum revolution by a model calculation, the
3 input parameter of which is, for example in belt embodiments, the current
4 longitudinal belt position.

5 Some embodiments use a combination of detection and prediction. For
6 example, in a belt embodiment, the belt's lateral position is measured at one
7 or two points along the belt (e.g. before the first and after the last print sta-
8 tion), and its lateral positions at each print station are then predicted by ex-
9 trapolation or interpolation, based on this measurement. The either detected
10 or predicted lateral positions are then input into a controller to compensate for
11 lateral shifts, as will be explained below.

12 Each print station includes at least one page-wide array of dot-forming
13 elements. A print station may be subdivided, along the width of the print sta-
14 tion, in several independent sub-arrays of dot-forming elements, called "print
15 heads". The print heads can be exchanged independently from one another,
16 which obviates a need to replace a complete print station in the event of a
17 fault which affects only a part of the print station. In ink-jet printer embodi-
18 ments, the dot-forming elements are orifices or nozzles, through which drop-
19 lets of liquid ink are ejected towards the recording medium. Embodiments
20 using other printing techniques have analogous dot-forming elements, for ex-
21 ample, in laser printers the dot-forming elements may be laser diodes di-
22 rected to a recording medium in the form of a charged photosensitive print
23 roller arranged to become discharged in illuminated areas. A charged toner is
24 then only taken up by the discharged areas and transferred to an output pa-
25 per sheet. To render the following description more illustrative, the specific
26 term "nozzles" is used hereinafter; it also stands for other dot-forming ele-
27 ments, such as light-emitting diodes.

28 In high-resolution printers, each print head has a very large number of
29 nozzles (typically in the order of 10^3 - 10^5). Some of a print head's nozzles will
30 inevitably become faulty in time. For example, in the case of ink jet printers,
31 faulty nozzles may be nozzles emitting in a false direction, or emitting no ink,
32 insufficient ink or abundant ink. Owing to the large number of nozzles in a
33 print head, typically some of them will be faulty, even if the error frequency

referring to an individual nozzle is small. It is economically not feasible to replace a print head, if only a few nozzles are faulty. However, in order to maintain good image quality the function of faulty nozzles is taken over by operative nozzles. Accordingly, an approach called "error hiding" has been adopted in the embodiments. It enables nozzle errors to be compensated without physically replacing any parts of the printing device. In order to achieve this, in some of the embodiments the nozzles are arranged in a redundant manner. For example, two identical print stations may be provided for each color. If a nozzle becomes faulty in one of the two print stations, its function can be taken over by one or more corresponding replacement nozzles of the other one of the two print stations, thereby hiding (i.e. effectively eliminating) the error. Shifting the task of a faulty nozzle to a corresponding (originally redundant) one is performed by using print masks, as will be explained below. In the following example, for sake of simplicity, it will be considered the case in which each nozzle can be replaced just by one corresponding redundant nozzle, which is the normal case when, for instance, the printer is printing at a printing resolution corresponding to the nozzle resolution. Clearly, when the printing resolution is lower than the nozzle resolution, more nozzles can print the same information and then more nozzles can be used for replacing the error nozzle. The same mechanisms and methods described in the following can still be applied to printer printing at resolutions allowing one nozzle to be replaced by a corresponding nozzle chosen out of a plurality of nozzles.

In the embodiments, the printing device is equipped with a nozzle-error detector, for example, in the form of a page-wide optical sensor array. In some embodiments, test print-outs are produced from time to time and viewed by the sensor array. The images printed as test print-outs are chosen such that they enable a missing or otherwise abnormal ink dot to be assigned to a certain nozzle in a certain print head, thereby enabling faulty nozzles to be identified. For example, dots from different print heads or rows of nozzles are not printed in an overlaid manner, but individually in the test print-out to enable the assignment mentioned above. In other embodiments, the information obtained by the optical sensor array by viewing images printed by the ensemble of print heads during the printer's normal operation is used to iden-

tify faulty nozzles. Owing to the fact that, typically, at least in some regions of the printed multicolor images only a single-color inking is required, comparing the actually printed images in such regions with the desired printed images also enables missing or otherwise abnormal ink dots to be detected and assigned to certain nozzles in certain print heads. Accordingly, in the latter embodiment faulty nozzles can be identified without test print-outs.

In still further embodiments, each print station is equipped with an individual nozzle-error detector which is arranged to directly detect faulty nozzles, e.g. by monitoring ink drop generation, but without "looking" at the print result on the paper. For example, in some embodiments, the nozzle-error detector is made up of a plurality of light barriers crossed by the ink drops expelled by the nozzles. A fault of a nozzle is indicated if the light barrier associated with a certain nozzle is not interrupted when the nozzle is fired. In other embodiments, a nozzle-error detector is provided which analyzes the noise produced by the nozzles upon operation; faulty nozzles are identified by missing or abnormal noise production. In still further embodiments, a capacitive nozzle-error detector is used which measure capacitive changes when a nozzle is fired, and detects faulty nozzles by missing or abnormal capacitive changes. Data representing information about faulty nozzles is stored and used to produce error-hiding print masks.

Print masks are (preferably two-dimensional, but can also have three or more dimensions) control tables (or patterns) for controlling the activity of the individual nozzles for the individual rows of the image to be printed. The print masks control the distribution of print activity between redundant nozzles or drum turns, and also control the error hiding. The print masks are independent of a particular image to be printed, i.e. the particular image information is carried by the input image data (but they may depend on the image type). Each print station has its individual print mask or masks. In practice, when a print stations segmented into print heads, the print mask of a print station may be correspondingly segmented, so that each print head may have its own print mask. However, the terminology used herein refers to a "print mask" as the print mask of an entire print station (which may actually be an assembly of smaller print masks, each associated with a print head). For example, the

1 print mask of a certain print station defines each nozzle of this print station to
2 be "enabled" or "disabled", which means that the respective nozzle is enabled
3 to print or remains inactive. As a simple example, a logical AND is formed
4 between the input image and the print mask for each image dot; if, for a cer-
5 tain image in a certain line, the input image requires ink to be applied to the
6 dot (logical "1") and the print mask enables the corresponding nozzle (logical
7 "1") in this line, the nozzle is activated (i.e. it applies ink). However, if the input
8 image defines that no ink is to be applied (logical "0"), and/or the print mask
9 disables the nozzle (logical "0"), the nozzle is not activated (i.e. no ink is ap-
10 plied to this dot). In some of the embodiments, more complicated print masks
11 are used, for example, to achieve half-toning besides print-activity distribution
12 and error hiding. In these embodiments, more than one nozzle is provided for
13 each picture element (pixel) of the input image; for example, four nozzles are
14 provided for each pixel. By activating one, two, three or four of a pixel's noz-
15 zles, four different color densities can be printed (this technique is also called
16 "dithering"). The print mask for each pixel may be a threshold matrix which
17 defines that the respective nozzle is only enabled if the input image's color
18 density for this pixel is above the respective threshold. Accordingly, in the
19 embodiments using half-toning, the logical-AND procedure described above
20 may be replaced by a thresholding procedure. In some embodiments, sepa-
21 rate print masks for print-activity distribution with error hiding and halftoning
22 are used for every print station. The nozzle activity of a print station may then
23 be controlled by a logical combination of the separate print masks.

24 As already mentioned above, in the embodiments, the nozzles are pro-
25 vided in a redundant manner, or redundancy is achieved by multiple drum
26 turns to enable the print activity to be distributed and nozzle errors to be hid-
27 den. For example, in some embodiments, the redundancy is achieved by
28 doubling the number of single-color print stations, e.g. by providing two cyan,
29 magenta, yellow and black print stations, which are eight print stations in total.
30 In the embodiments, the print masks define how a printing task is distributed
31 between the redundant nozzles, i.e. which one of two redundant nozzles is
32 activated to apply ink to a particular dot, and which one is not activated. For
33 example, in the ideal case of print stations without any nozzle errors, the print

1 masks of two redundant print stations of one color which form a redundancy
2 group (which may also be represented by one and the same print station in
3 two different drum turns) may be arranged like complementary checkerboard
4 patterns. Such complementary checkerboard patterns equally distribute the
5 print task to the two print stations of a redundancy group and add up to a
6 complete coverage. More generally, the print masks of redundant print sta-
7 tions associated with each may be complementary patterns minimizing or re-
8 ducing blocks of contiguous dots or picture elements printed by each print
9 station, or during each drum turn. Distributing the print activity typically im-
10 proves the image quality achieved since, for example in ink jet printing, it en-
11 ables the ink applied by the first print station, or during the first drum turn, to
12 dry until the print process is continued, thereby enabling more ink to be ap-
13 plied, which may improve the color intensity. Furthermore, combining error
14 hiding with distributed printing provides better quality than printing only miss-
15 ing columns of defective nozzles in a second pass, since such columns may
16 be visible in the final printed image. Although a symmetric distribution
17 (50%:50% between two redundant print stations) is advantageous, in some
18 embodiments an asymmetric distribution of the print activity is chosen, for
19 example 70% of the print activity by the first print station, or in the first drum
20 turn, and only 30% by the second print station, or in the second turn, in par-
21 ticular in embodiments in which not all faulty nozzles of the second print sta-
22 tion, or the second turn, are hidden by the print activity of the first print station,
23 or in the first turn, as will be explained below.

24 If faulty nozzles are present, the print masks which distribute the print
25 activity between the nozzles of a redundancy group, or between drum turns,
26 in a normally regular manner, are modified so as to hide the nozzle errors.
27 For example, assuming that one nozzle in one of the print stations of a re-
28 dundancy group has become faulty. Then, in the print mask associated with
29 this print station, all fields in the print-mask row corresponding to the position
30 of the faulty nozzle are set to "0". Thereby, for example, the regular checker-
31 board pattern mentioned above is disturbed. In the print mask of the other
32 print station of the redundancy group, all fields of the corresponding print-
33 mask row are set to "1", so that the two masks are complementary. Accord-

1 ingly, the faulty nozzle is disabled, and its print task is taken over by the cor-
2 responding other nozzle of the redundancy group. The nozzle error will not
3 appear in the print-out. In the embodiments, the printing device is arranged,
4 upon identification of new nozzle errors, to calculate new print masks taking
5 into account such newly discovered nozzle errors and to replace the currently
6 used print masks by these updated ones.

7 As explained above, in the embodiments, lateral shifts of the recording
8 medium detected at a certain print station are compensated by data shift op-
9 erations, so as to maintain the registration of the individual images printed
10 onto each other. However, as can be seen from the example above, the print-
11 ing activity of the print stations belonging to a redundancy group, or during
12 different passes, are correlated; accordingly, if one requires the print masks
13 associated with redundant print stations to be complementary and provide full
14 coverage, when combined, at least the print masks of the print stations form-
15 ing a redundancy group are correlated.. Due to the print masks' correlation, it
16 is generally not sufficient only to shift the input image in order to compensate
17 for a lateral recording medium displacement at a particular print station. This
18 is because shifting only the image data without shifting the print mask of the
19 respective print station would result in an image in which some dots are erro-
20 neously left blank, and on other dots ink would be applied twice. On the other
21 hand, if the print mask associated with the respective print station were
22 shifted together with the image, it would no longer be complementary to the
23 print mask of the other print station of the redundancy group. This, in turn,
24 would cause some dots to be left blank or inked twice. Therefore, if a lateral
25 displacement is detected at a certain print station, the current print mask as-
26 sociated with this print station is replaced by another print mask relating to the
27 changed lateral position. This new print mask, in principle, is a shifted print
28 mask, in which the amount of shift corresponds to the detected lateral shift of
29 the recording medium. However, those parts of the print mask which corre-
30 spond to faulty nozzles of the respective print station are not shifted together
31 with the whole print mask. Rather, in the new print mask these parts are lo-
32 cated at a different position within the mask, so as to take into account that,
33 although the mask has been shifted, that the faulty nozzles have not been

shifted. Owing to the correlation of the print masks of the print stations of a redundancy group, the print mask of the other print stations of the redundancy group are also replaced by new complementary print masks, i.e. print masks which take into account that the position of the faulty nozzles have effectively been changed in the print mask of the print station at which the lateral shift has been detected. In other words, the print masks of all print stations of a redundancy group, between which a relative lateral shift of the recording medium has been detected are replaced by new print masks taking into account this lateral shift.

With regard to error hiding, the correlation between two print stations forming a redundancy group requires the first print station (or the print station during the first pass) to take over the printing activity of the second print station (or the laterally shifted position of the print station during the second pass) for those columns in which a second print station (or the print station at the laterally shifted position) has faulty nozzles. Vice versa, the second print station (or the print station during the second pass) has to take over the print activity of the first print station (or the print station during the first pass) for those columns in which the first print station has faulty nozzles. In principle, this requires not only the print mask of the second print station of a redundancy group (or the second pass), but also the print mask of the first print station (or the first pass) to be replaced by print masks relating to the new relative lateral position, in order to make the two print masks fully complementary and achieve complete error hiding. However, there are a couple of cases in which the first print station has already printed its partial image, or a part of it. What has already been printed, cannot be changed any more. In particular, for that part which the first print station already printed, it will not be able to take over the printing activity of the second print station's faulty nozzles, since these nozzles will now, after the occurrence of the relative lateral shift, be effectively positioned at different lateral positions from the ones assumed by the first print station before the lateral shift occurred. Only the second print station is able to still take into account the relative lateral shift and take over the print task of the first print station's faulty nozzles. Therefore, using a new print mask relating to the new relative lateral position at the second print station (or

1 the second pass) enables a partial error hiding, but a perfect error hiding will
2 generally not be achievable in such cases of a "delayed" detection of a rela-
3 tive lateral replacement. For example, when a belt of a belt conveyor changes
4 its skew angle resulting in a relative lateral displacement at the second print
5 station, that part of the image which has already been printed by the first print
6 station, but has not yet been printed by the second print station, will not be
7 affected any more by the new print mask for the first print station relating the
8 new relative lateral position, but will only be affected by the new print mask for
9 the second print station. Therefore, for a "transitional phase" (which lasts until
10 the print-out of first print station printed with the new print mask reaches the
11 second print station), no complete error hiding will be achieved. Complete
12 error hiding will be achieved for that part of the image printed by the first print
13 station after the first print station's print mask has been replaced by another
14 print mask relating to the changed relative lateral position.

15 In printing devices in which redundancy is achieved by multiplying the
16 number of print stations, the length of this transitional region corresponds to
17 the distance between the first and last print station of a redundancy group,
18 and may thus be minimized by arranging the print stations belonging to a re-
19 dundancy group as close as possible in the advance direction.

20 In embodiments in which the redundancy is achieved by multiplying the
21 number of passes, the transitional region tends to be longer. For example, if
22 the paper on the drum of a drum conveyor is laterally displaced in the middle
23 of the first drum revolution, the already printed first half of the image printed
24 during the first revolution is a "transitional region". In the case in which the
25 relative lateral displacement between print station and recording medium
26 happens when the print station is laterally shifted between the first and sec-
27 ond revolution (which may be the case when this lateral shift of the print head
28 is not controlled to the required precision), then the entire image is the "transi-
29 tional region" in which only partial error hiding will be achieved.

30 Incidentally, in some of the embodiments the print masks are only re-
31 placed if a different relative lateral shift is detected between two print stations
32 of a redundancy group (i.e. if the belt of a belt conveyor changes its skew an-
33 gle). However, if the same lateral shift is detected for two such print stations,

1 only the image data are shifted, but the old print masks continue to be used.
2 In other embodiments, the print masks are even replaced in the latter case
3 (i.e. in the case in which both print stations of the same redundancy group
4 detect the same lateral shift). For example, if additional half-toning masks are
5 used and combined with described error-hiding masks, as mentioned above,
6 lateral sub-pixel shifts may be compensated by replacing the combined
7 masks of all print stations subjected to the lateral shift by new print masks
8 relating to the lateral position changed in common.

9 In some of the embodiments in which the redundancy is achieved by
10 multiplying the number of print stations of the same color, the replacement of
11 print masks upon detection of a lateral recording medium displacement is per-
12 formed from page to page. If a lateral displacement occurs during the printing
13 of a particular page, the print masks will only be replaced by new print masks
14 relating to the changed lateral position at the start of the next page. Since one
15 print process may include more than one page to be printed, the print mask
16 replacement may take place within a print process. In some of the embodi-
17 ments in which the redundancy is achieved by multiplying the number of
18 passes, the replacement of print masks upon detection of a lateral recording
19 medium displacement is performed for the next pass; i.e. the current print
20 mask will only be replaced by new print mask relating to the changed lateral
21 position at the start of the next pass. In other embodiments, the print mask
22 replacement is performed within the currently printed page or pass upon de-
23 tection of a lateral displacement. For example, a page to be printed is subdi-
24 vided into several transversely extending blocks (e.g. four blocks). If a lateral
25 position change occurs within one of those blocks, the currently used print
26 masks are replaced by new ones relating to the changed lateral position at
27 the start of the next block.

28 In some of the embodiments, the new print masks relating to a detected
29 changed lateral position are calculated in real time ("on the fly") during the
30 print process. In these embodiments, the newly calculated print masks re-
31 place the previous ones. For example, the previous print masks may be
32 dropped, e.g. overwritten by the newly calculated ones.

33 However, in high-resolution printers with a large number of nozzles, cal-

1 calculating a new print mask relating to a changed lateral position may be time-
2 consuming, even if a high-performance processor is used. In order to enable
3 a fast compensation upon detection of a lateral shift, other embodiments are
4 equipped with a print-mask memory arranged to store print masks for different
5 lateral recording medium positions. Such sets of print masks for different lat-
6 eral positions are, for example, pre-calculated upon detection of new nozzle
7 errors, and stored in the print-mask memory. If, during a print process, a lat-
8 eral position change is detected, the controller reads in and uses those print
9 masks from the stored set of print masks which relate to the changed lateral
10 position. Reading pre-calculated print masks from memory can be performed
11 much faster than calculating new print masks. Therefore, the latter embodi-
12 ments enable a nearly instantaneous compensation of lateral position
13 changes in high-resolution printers.

14 In embodiments in which the print masks are only replaced if a different
15 lateral displacement for the two print stations of a redundancy group has
16 been detected, it is sufficient to pre-calculate and store only a set of print
17 masks relating to the possible differences of lateral displacements. This is a
18 relatively small number of print masks to be pre-calculated and stored. For
19 example, if then a lateral displacement of two pixels is detected at the first
20 print station, and a displacement of three pixels at the second print station,
21 the common displacement by two pixels is taken into account by shifting only
22 the image data by said two pixels. The remaining 1-pixel difference-
23 displacement is taken into account by using the pre-calculated print mask for
24 a 1-pixel difference-displacement compensation, explained in detail in con-
25 nection with Fig. 4f below. For example, if the embodiment is a 1200 dpi reso-
26 lution printer, the distance between dots of two adjacent nozzles is about
27 0.0008 inch, one print mask is necessary to compensate every 0.0008 inch
28 lateral-difference-position change. Assuming that the maximum lateral-
29 difference-position change of the embodiments is +/-0.004 inch, about 11 dif-
30 ferent sets of print masks are pre-calculated and stored. In other embodi-
31 ments in which all lateral displacements (including equal displacements at the
32 two print stations of a redundancy group) require a print mask replacement for
33 the particular absolute displacement, print masks relating to all possible abso-

1 late displacements are pre-calculated and stored. Due to the number of pos-
2 sible combinations and such absolute displacements, the number of print
3 masks to be pre-calculated and stored is relatively large.

4 As can be taken from the explanations above, redundancy may not only
5 be achieved by multiplying the number of (physical) print stations of each
6 color, but also by multiplying the number of passes, for example by perform-
7 ing two or more revolutions of the print medium in a drum system (although,
8 of course, also in a drum system redundancy may be achieved by providing
9 more than one physical print station of each color). The explanations made
10 herein, in particular with regard to print activity distribution and error hiding by
11 print masks and their replacement methods, also apply to such multi-pass
12 systems in an analogous manner. However, in order to enable error hiding, a
13 relative lateral shift between the print station or stations and the recording
14 medium is actively performed between the passes. For example, if nozzle No.
15 10 is defective (assuming that the nozzles are numbered from left to right)
16 and the print station is shifted by four pixels to the left before between the first
17 and second drum revolutions, the task of the defective nozzle is taken over by
18 nozzle No. 6 during the second revolution. The "redundancy group" then is
19 formed by the one print station under consideration, including its print activity
20 during the two or more passes. Different print masks are associated with the
21 different passes forming the redundancy group. In a single-color printing de-
22 vice, there may be only one print station (and one redundancy group); in
23 multi-color systems there may be several print stations of different colors, e.g.
24 four print stations (i.e. four redundancy groups).

25 Although the relative lateral shift of the print station(s) between the
26 passes is actively carried out in order to enable error hiding, it is nevertheless
27 considered as a lateral displacement of the sort described above, which is
28 taken into account by replacing a currently used print mask by another one
29 relating to the new relative lateral position. In particular, in embodiments in
30 which the active print-station displacement is not mechanically controlled to
31 the print precision, the actual amount of performed lateral print-station shifting
32 is detected by a lateral-position detector and handled in manner analogous to
33 unwanted lateral belt displacements in a belt conveyor.

1 Returning now to Fig. 1, it shows a printing device 1 in which a recording
2 medium 2 is conveyed in an advance direction 3 by a conveyor belt 4. The
3 recording medium 2 is attached to belt 4, for example, by means of an hold-
4 down vacuum system arranged below the surface of the belt 4. Page-wide-
5 array print stations 5 are arranged along the conveyor belt 4 to produce an
6 image from print data provided by a controller 6. In order to keep Fig. 1 sim-
7 ple, it shows only four print stations 5 for two colors, namely print stations C1
8 and C2 for "cyan", as well as print stations M1 and M2 for "magenta". The
9 print stations of the same color (C1/C2 and M1/M2) are redundant, and the
10 corresponding pairs each form a redundancy group. Typically, a printer has
11 four colors with eight print stations, forming four redundancy groups. The con-
12 troller 6 includes a print-mask calculator 7, a print-mask memory 8, and a
13 print-data generator 9. A page-width nozzle-error detector 10 views printed
14 images and forwards data representing the printed images to the controller 6.
15 Each print station 5 is equipped with an encoding-mark sensor 11 responsive
16 to encoding marks 10 arranged at a longitudinal edge of the conveyor belt 4.
17 The encoding marks 12 are indicative of the belt's lateral position. Sensor
18 signals representative of the lateral position are input into the controller 6.

19 The print-mask calculator 7 calculates new sets of print masks upon de-
20 tection of new nozzle errors, based on data provided by the nozzle-error de-
21 tector 10, and stores an updated version of the print-mask set in the print-
22 mask memory 8. The print-data generator 9 receives image input-data 13
23 from the outside and transforms them to print data sent to the print stations 5
24 to control nozzle activity during the print process. To this end, it uses the lat-
25 eral-position information provided by the encoding-mark sensors 11 to select
26 those print masks from the print-mask memory 8 which relate to the current
27 lateral positions, and combines the image input-data 13 with these print
28 masks to generate the print data. If a lateral position change is detected, the
29 currently used print masks are replaced by other print masks from the print-
30 mask memory 8 which relate to the changed lateral position.

31 Fig. 2a illustrates an embodiment of a lateral-position detector arrange-
32 ment with a sensor 11 arranged to detect line-like encoding marks 12 which
33 extend in the longitudinal (or advance) direction 3. The sensor 11 extends in

1 the lateral direction. It is responsive to lateral shifts of the encoding marks 12.

2 In Fig. 2b an exemplary lateral shift is illustrated and denoted by "14".

3 Fig. 3a illustrates another embodiment of a lateral-position detector ar-
4 rangement based on encoding marks 12 which are formed by two lines, one
5 of which extends in the lateral direction, and the other one in an angle (for
6 example of 45°) with respect to the first line. The sensor 11 has two sensor
7 elements responsive to the two lines. The delay between the two signals as-
8 sociated with such an angled encoder mark 12 represents the lateral position
9 of the conveyor belt, since a lateral position change illustrated in Fig. 3b (de-
10 noted by "14") will result in a correspondingly changed delay between these
11 two signals.

12 Fig. 4 illustrates an example of how an input image 20 is printed by two
13 print stations 5, 5', which form a redundancy group, by using print masks 21,
14 21'. The input image 20 is represented by image input-data 13 (Fig. 1). The
15 print mask 21 is associated with the first print station 5, and the print mask 21'
16 is associated with the second print station 5' of the redundancy group. Fig. 4
17 also illustrates an area 22 inked by the first print station 5, as well as an area
18 22' inked by the second print station 5'. It also illustrates the finally printed
19 image 23 which is a combination of the inked areas 22 and 22'. The controller
20 6 (Fig. 1) performs a logical AND of the input image 20 and the print mask 21,
21 or 21', of the respective print station 5, or 5'. The logical value "1" is illustrated
22 by black or gray squares in Fig. 4, and the logical value "0" is illustrated by
23 white squares. The print masks 21, 21' have a generally checkered pattern
24 and are normally complementary so that a combination of both print marks
25 21, 21' would lead to a completely gray area (i.e. an area having only logical
26 values "1").

27 In Fig. 4, it is assumed that one nozzle of the second print station 5' is
28 faulty; the position of the faulty nozzle is illustrated by a white field in the print
29 station 5'. The generally checkerboard-like patterns of the print masks 21, 21'
30 are "disturbed" so as to hide the faulty nozzle of the first print station 5'.

31 Fig. 4a illustrates the case in which no lateral displacement of the belt 4
32 (Fig. 1) has occurred. The row of print mask 21' that corresponds to the faulty
33 nozzle in the print station 5' (the fifth nozzle seen from the top in Fig. 4) is

1 completely set to "0", rendering the faulty nozzle of the second print station 5'
2 inactive. Correspondingly, the same row of the first print station's comple-
3 mentary print mask 21 is completely set to "1", which means that the corre-
4 sponding nozzle of the first print station 5 takes over the function of the faulty
5 nozzle. Both print masks 21, 21' are complementary and, when combined,
6 cover the entire print area. As illustrated in Fig. 4a, the area 22 inked by the
7 first print station 5 is a checkerboard-like part of the input image 20, wherein
8 the fifth row is completely printed. The area 22' inked by the second print sta-
9 tion 5' is the complementary checkerboard-like pattern within the input image
10 20, wherein said row (which has been completely printed by the first print sta-
11 tion 5) is left blank. The combination of the inked areas 22, 22' is the actually
12 printed image 23. As can be seen in Fig. 4a, the printed image 23 equals the
13 input image 20. Consequently, the nozzle error of the first print station 5 is
14 perfectly hidden.

15 Figs. 4b to 4f illustrate cases in which the print medium is laterally
16 shifted between the first print station 5 and the second print station 5'. In the
17 example of Fig. 4, the print medium is shifted by one pixel to the top of Fig. 4,
18 which is illustrated by two relatively shifted plots of the inked area 22, one of
19 which being provided with a wavy arrow indicating the lateral shift of the print-
20 medium.

21 Fig. 4b illustrates what will happen if no activity is taken to compensate
22 the lateral displacement of the print medium, i.e. if neither the image data are
23 shifted nor the print masks are shifted or changed. Since the assumed lateral
24 displacement only occurs after the first print station 5, the inked area 22 pro-
25 duced by the first print station 5 is the same as the one in Fig. 4a. However,
26 due to the displacement of the print medium by one pixel (in the upward direc-
27 tion in Fig. 4), the second print station's print mask 21' is effectively (i.e. relat-
28 ing to the occurred lateral shift of the print medium) no longer complementary
29 to the first print station's print mask 21. The inked area 22' is produced by the
30 second print station 5' with an effective displacement of one pixel downwards
31 relative to the already inked area 22. As a consequence of the fact that the
32 two, mainly checkerboard-like, print masks 21, 21' are effectively not com-
33 plementary, many of the pixels of the printed image 23 are inked twice, and

1 many others are left blank, resulting in an image of relatively poor image qual-
2 ity.

3 Fig. 4c illustrates what will happen if only the image data are shifted for
4 the second print station 5' in order to compensate the detected lateral shift of
5 the recording medium. In Fig. 4c, a corresponding shift of the image data rela-
6 tive to the second print station 5' by one pixel in the upward direction is indi-
7 cated by an overlaid shifted input image data 20 (shown in gray) and by an
8 arrow above the field 20. The second print station's print mask 21' is effec-
9 tively not complementary to the first print station's print mask 21, as in Fig. 4b.
10 Again, as a result, many of the pixels of the printed image 23 are inked twice,
11 and many others are left blank, resulting in an image of relatively poor image
12 quality, similar to the one obtained in Fig. 4b.

13 Fig. 4d illustrates what will happen if only the print mask 21' of the sec-
14 ond print station 5', but not the input image data 20, is shifted upwardly by
15 one pixel in order to compensate the detected lateral shift of the print medium
16 (the shift of the print mask 21' is indicated by arrow in Fig. 4d). A certain im-
17 provement is now achieved, owing to the fact that the regular checkerboard-
18 like parts of the print masks are now again complementary (relating to the
19 occurred lateral shift of the print medium). However, as the positions of faulty
20 nozzles are physically fixed at the respective print station (in Fig. 4, the pos-
21 tion of the second print stations' faulty nozzle is fixed at the position of the
22 fifth nozzle), such a shift of the print mask 21' does not cause the faulty noz-
23 zle to be shifted in unison. Rather, the faulty nozzle stays where it is, and the
24 shifted print mask 21' therefore no longer corresponds to the faulty-nozzle
25 situation. As can be seen in Fig. 4d, the shifted print mask 21' has a blank
26 row, although the corresponding nozzle of the second print station is opera-
27 tive, but has a normal checkerboard row at the position of the faulty nozzle.
28 As a consequence, no complete error hiding is achieved. Nevertheless, the
29 final printed image 23 has a better image quality than the one of Figs. 4b and
30 4c, due to the effective complementarity of the print masks 21, 21' in their
31 regular parts.

32 Fig. 4e illustrates what will happen if not only the input image 20 is
33 shifted (as in Fig. 4c), but also the print mask 21 of the second print station 5'

1 is shifted upwardly (as in Fig. 4d) by one pixel in order to compensate the de-
2 tected lateral shift. Again, no complete error hiding is achieved. The printed
3 image is similar to the one obtained in Fig. 4d. This illustrates that a complete
4 error hiding is generally not achieved by simply countershifting the input im-
5 age and the print mask of a print station at which a lateral shift is detected.

6 Fig. 4f illustrates the full error-hiding approach. Both the input image
7 data 20 and the second print mask 21' are shifted upwardly by one pixel, as
8 illustrated in Fig. 4e. In addition, the changed position of the faulty nozzle
9 relative to the shifted recording medium is taken into account in the new print
10 mask 21'. As can be seen in Fig. 4f, the print mask's row which is entirely set
11 to the value "0" is now at the sixth row (rather than its fifth row), correspond-
12 ing to the changed relative position of the faulty nozzle. Since the print mask
13 21, 21' of the redundancy group ought to be complementary, also the first
14 print mask 21 is replaced by a new print mask 21 the sixth row of which
15 (rather than the fifth row) is entirely set to the logical value "1". The new print
16 mask 21 causes the first head to print all pixels which the second print sta-
17 tions defective nozzle cannot print; in turn, the new print mask 21' disables
18 only the defective nozzle. As can be seen in Fig. 4f, the finally printed image
19 equals the input image 20. Accordingly, by the print-mask replacing
20 method illustrated in Fig. 4f, complete error hiding is achieved. Fig 5. shows a
21 flow diagram of two exemplary processes relating the lateral-position-change
22 compensation with error-hiding print masks described above. The process
23 illustrated at the left-hand side of Fig. 5 runs from time to time between print
24 jobs. It starts with printing a test pattern, which is observed by the nozzle-error
25 detector 10 (Fig. 1). The sensor data is analyzed to identify faulty nozzles. If
26 new faulty nozzles are detected, a new set of print masks is calculated which
27 also takes into account the new faulty nozzles. The set includes correlated
28 print masks for each print station and each possible set of lateral positions of
29 the recording medium at the different print stations. The calculated new set of
30 print masks is stored in the print-mask memory.

31 The process illustrated at the right-hand side of Fig. 5 runs during print
32 processes, for example from page to page, or several times within a page. In
33 Fig. 5, it is assumed that certain print masks are already in use for a given

1 lateral position of the recording medium. During the print process, encoding
2 marks indicative of the recording medium's lateral position are constantly de-
3 tected, and the recording medium's position is determined based on this. If a
4 lateral position change is detected, the pre-calculated print masks associated
5 with the new lateral position of the recording medium are recalled from the
6 print-mask memory. Printing is to be continued with the new print masks in-
7 stead of the previous ones.

8 Fig. 6 illustrates a printing device 1' having a conveyor in the form of a
9 drum 31. A recording medium 2 is attached to the drum 31, for example by
10 means of a vacuum system within the drum 31. Upon rotation of the drum 31,
11 the recording medium is moved past a page-wide-array print station 5'. In or-
12 der to keep Fig. 6 simple, only one print station 5' is shown; however, a multi-
13 color printer will typically have a number of single-color page-wide-array print
14 stations corresponding to the number of colors used, i.e. typically four or six
15 print stations. The print station 5' is equipped with an array of ink-jet nozzles;
16 it may be segmented in print heads. A page-wide nozzle-error detector 10' is
17 attached to the print station 5 and enables faulty nozzles to be directly de-
18 tected, e.g. using a light-barrier array, a noise detector array or a capacitance-
19 change detector array.

20 An actuator 32, e.g. a piezo actuator, is provided which enables the print
21 station 5' to be shifted in the lateral (i.e. axial) direction in a controlled man-
22 ner. The actuator 32 is equipped with a print-station-displacement-
23 measurement device which measures the print station's current lateral posi-
24 tion. The actuator 32 is controlled by a controller 6' of the printing device 1',
25 and the print-station-displacement-measurement device supplies its signals
26 back to the controller 6'.

27 In the printing device 1' of Fig. 6, redundancy is achieved by rotating the
28 recording medium more than once past the print station 5', and by laterally
29 shifting the print station 5' between the drum revolutions. The controller 6'
30 provides the print station 6' with a first print mask for the first revolution, and
31 with a second, complementary print mask for the second revolution (in the
32 case of two-fold redundancy).

33 A recording-medium sensor 11' is arranged to measure the recording

1 medium's current lateral position near the print station 5'. It is, for example, an
2 optical surface-recording arrangement which detects and records surface im-
3 ages of the recording medium (e.g. of the fiber structure of a paper sheet)
4 during the drum rotation. It detects lateral displacements of the recording me-
5 dium by comparing currently detected surface images with stored surface im-
6 ages recorded during the previous revolution(s). In some embodiments, two
7 such sensors are positioned at a small distance along the circumference of
8 the drum. The second sensor detects lateral displacements of the recording
9 medium by comparing currently detected surface images with stored surface
10 images just recorded by the first sensor. This enables lateral displacements of
11 the recording medium to be immediately (i.e. within the currently printed
12 page) detected and corrected (by replacing the current print mask by a new
13 one relating to the changed lateral position). Information obtained about lat-
14 eral displacements of the recording medium are input into the controller 6'.

15 The controller 6' provides the print station 5' with image data to be
16 printed and print masks controlling the print activity. The print masks are ar-
17 ranged such that print activity distribution and error hiding is achieved, as ex-
18 plained in connection with Fig. 4 (however, a complete error hiding will not be
19 achieved in what has been called the "transitional region" above). If the print
20 station's lateral position is changed by the actuator 32 and/or an unintended
21 lateral displacement of the recording medium 2 relative to the drum31 is ob-
22 served, the currently used print mask is replaced by another one relating to
23 the new lateral position of the print station 5', measured by the print-station-
24 displacement-measurement device, and/or the recording medium 2, meas-
25 ured by the recording-medium sensor 11'. The new print mask relates to the
26 new relative lateral position between the print station 5' and the recording
27 medium 2. The mechanisms of the print activity distribution, error hiding and
28 print mask generation and replacement are analogous to what has been de-
29 scribed above, also in connection with Fig. 4. The controller 6' is analogous to
30 the controller 6 of Fig. 1; for example, it has a print mask calculator, a print
31 mask memory, and a print data generator.

32 Faulty nozzles are observed by the nozzle-error detector 10', and new
33 sets of print masks which take into account the observed faulty nozzles are

1 pre-calculated and stored in the print mask memory, as described above, also
2 in connection with the left-hand side of Fig. 5. During the print process, after
3 having determined an (intended or unintended) shift of the relative lateral po-
4 sition between the print station 5' and the recording medium 2, the print mask
5 associated with the new relative lateral position are recalled from the print
6 mask memory and are used during the print process, as described above,
7 also in connection with the right-hand side of Fig. 5.

8 Thus, the multi-station and multi-pass embodiments described above, in
9 particular the devices 1, 1' of Figs. 1 and 6, are analogously arranged and
10 controlled, and work in an analogous manner. That parts of the description of
11 features of the multi-station embodiments which have not been expressly
12 mentioned in connection with the multi-pass embodiments, therefore also ap-
13 ply in an analogous manner to the multi-pass embodiments.

14 The embodiments described enable lateral-position changes of the re-
15 cording medium to be compensated in printing devices using error-hiding print
16 masks. The compensation may be performed in real time during the print
17 process. Thereby, image quality is improved.

18 All publications and existing systems mentioned in this specification are
19 herein incorporated by reference.

20 Although certain methods and products constructed in accordance with
21 the teachings of the invention have been described herein, the scope of cov-
22 erage of this patent is not limited thereto. On the contrary, this patent covers
23 all embodiments of the teachings of the invention fairly falling within the scope
24 of the appended claims either literally or under the doctrine of equivalents.